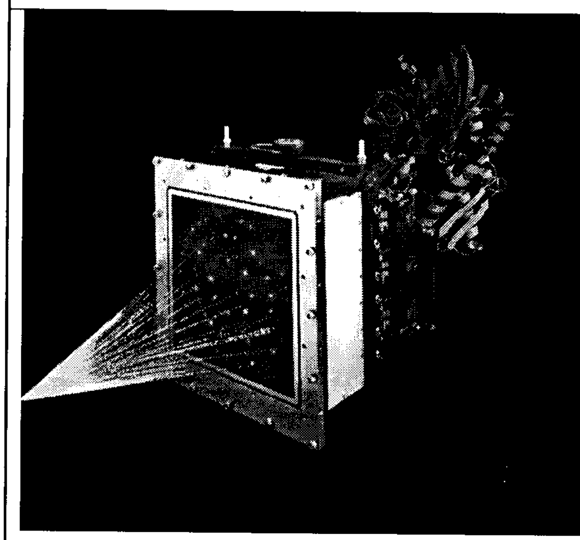
CCD (CHARGE-COUPLED DEVICE) DETECTORS FOR CRYSTALLOGRAPHY



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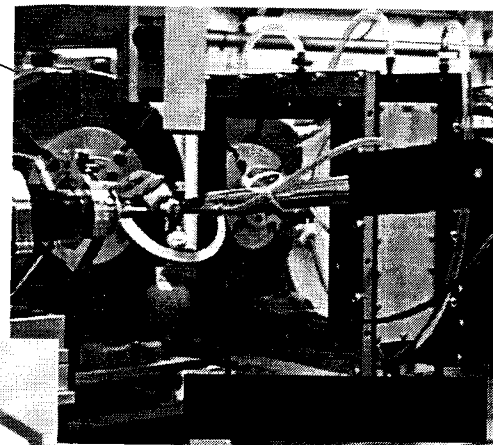
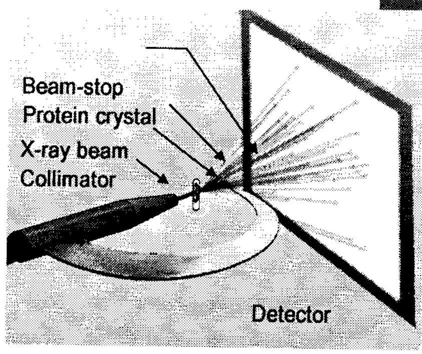
CCD (Charge-Coupled Device) Detectors
for Crystallography

- Detector requirements for macromolecular diffraction measurements
- Overview of CCD detector technology
- Quantitative analysis of performance parameters
- Future directions of CCD detector development

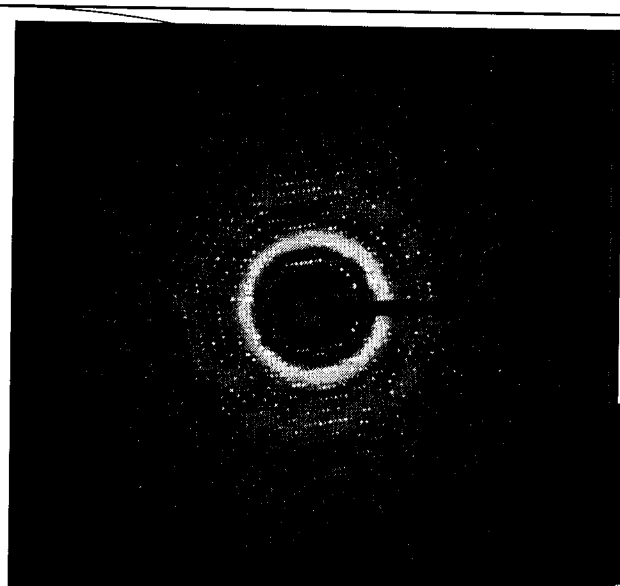
Protein Crystallography Setup (APS-SBC 19BM)





Typical parameters:

X-ray energy range: 6-20keV
X-ray intensity (main beam): 10^{13} XPh/s
crystal volume: 10^{-3} mm^3
crystal to detector distance: 70 - 900mm
exposure time: 0.1s - 20s
number of frames / data set: 100 - 1000



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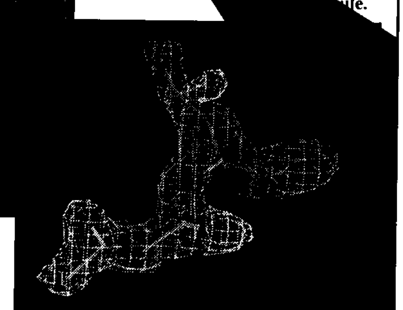


MAD: Multiple-wavelength Anomalous Dispersion measurement at 2 - 4 different energy

CCD Detectors for protein crystallography:

Integrating type detectors

Advantages:

- virtually unlimited count-rate capability
- very high pixel count (> 10^6 pixels)
- simple readout
- timing capability

Disadvantages:

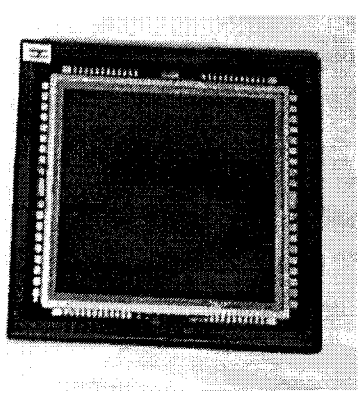
- readout and dark current noise introduces err[...] low intensities
- dead during read[...]

Does the data quality improve significantly, by using <u>counting</u> detectors ?

- Dynamic range: **>20,000** at 10^5/sec XPh/s count-rate in CCD detectors
  In counting detectors this would require < 5 pps/pixel false pulses
- The scattered X-ray background is the dominant noise source usually ...
- At high count rates, accuracy is limited in CCD detectors to ~0.3..0.5%.

Charge Coupled Device is a solid-state imager:

- converts light to electron-hole pairs
- stores charge pattern in picture elements (pixels)
- shifts charge packets in pixels to output(s)
- converts charge to voltage on output

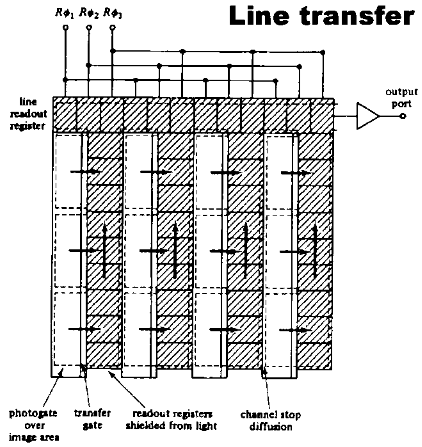


Thompson-CSF (now ATMEL)
2048 x 2048 pixels
Pixel size: 13 x 13 um
Imaging area: 28 mm x 28 mm

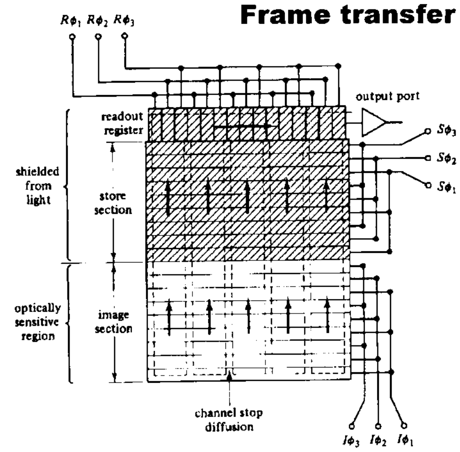
Readout structures:

- line transfer
- frame transfer
- full frame
- single/multiple readout amplifiers

Line transfer



Frame transfer



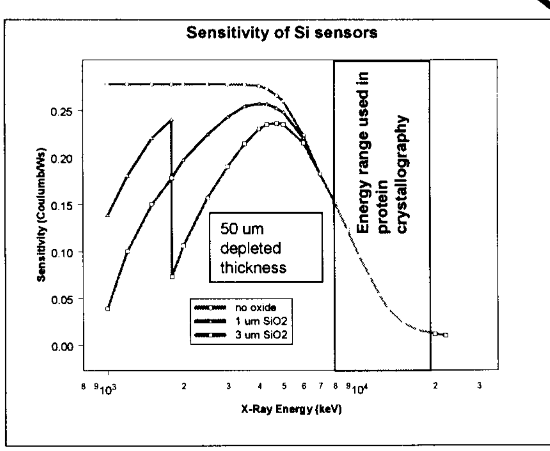
Direct detection of X-ray by CCD's:

Low sensitivity (8keV-20keV)

Radiation damage

Too high gain

etc.



Indire

X-ray

↓

Visible lig

↓

electrons

CCD Detector technologies

Single Fiber-Optic Taper Detectors

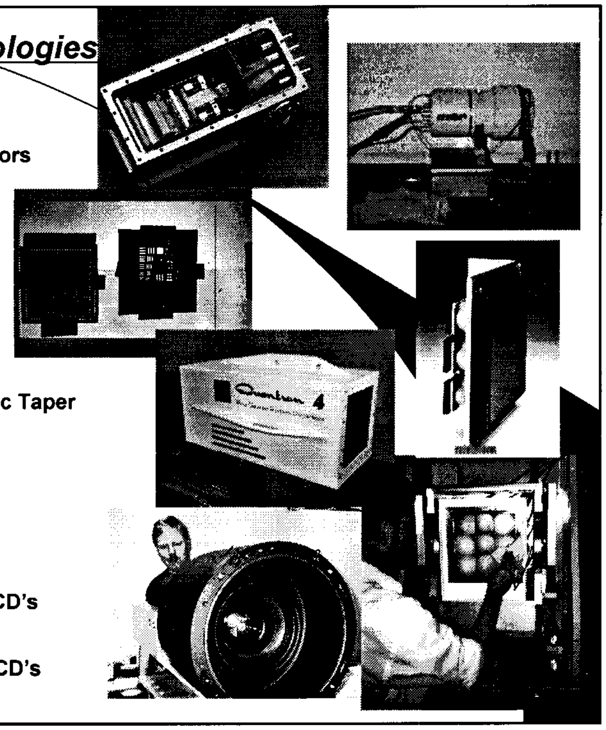
Fiber-Optic Faceplate Detectors

Multiple (Mosaic) Fiber-Optic Taper Detectors

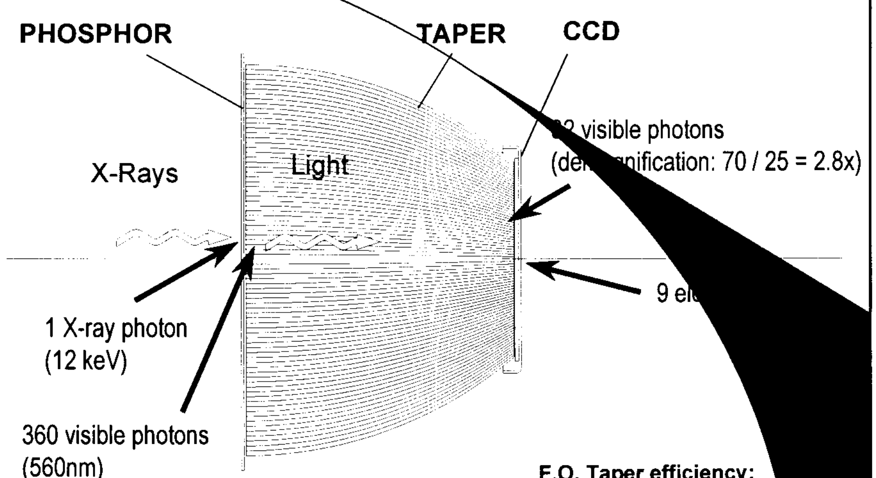
Lens Coupled Detectors

Direct X-ray detection with CCD's

Time-resolved imaging with CCD's



Demagnification by fiber-optic taper



F.O. Taper efficiency:
0.7 x (Input area / Output area)

CCD Quantum Efficiency (front illuminated):
0.25 - 0.30 at 560nm

GENERAL DETECTOR REQUIREMENTS

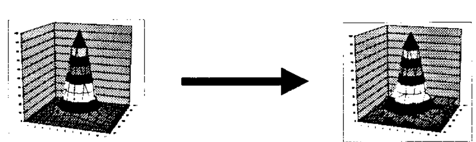
• **Very large dynamic range**	> 10,000 / pixel
• **low noise**	< 20 electrons rms / pi … bined noise)
• **high saturation level**	> 350,000 electrons / pixe
•**Large area**	> 200 mm x 200 mm
• **High sensitivity**	> 5 electrons / XPh
• **Very high "count rate" capability**	>106 electrons / pixel / s
• **Good linearity**	< 0.5% deviation from linearity
• **High stability**	< 0.5% gain drift, < 0.1% baseline d
• **Short readout time**	< 2 seconds / frame

Comparing detector parameters

Meaningful characterization of detector performance should be based on how the quality of the collected data is affected by the detector parameters?

Input:
Typical diffraction peak on the detector face

Output:
Observed diffraction peak



Quantitative comparison of the

- **conversion gain, noise and saturation level**
- **sensitive area (size) of the the detector**

Conversion Gain:

Number of photoelectrons generated in the CCD pixels by 1 X-ray photon (typically at 12 keV)

Conditions:

Sample size: 150 um x 150 um

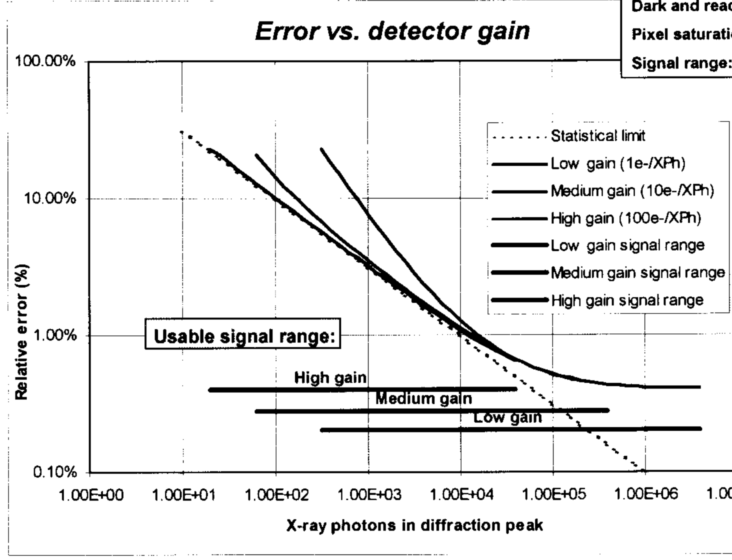
Integration: 5x5 pixels

Integral / peak pixel value: 10x

Dark and read noise / pixel: 20 e- rms

Pixel saturation: 400,000 e-

Signal range: 20% error to saturation



Conversion gain of available detectors:

ADSC Q210: 3.4 e-/XPh

SBC-2: 8 e-/XPh

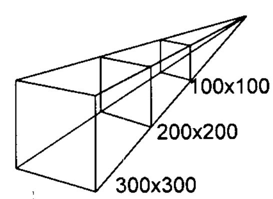
Bruker lens: 7e-/XPh?

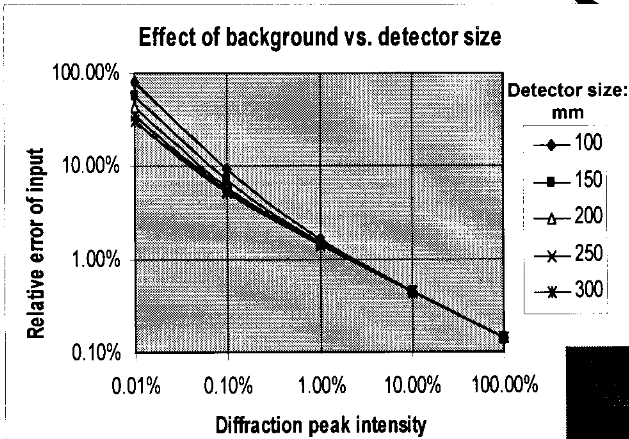
(0.65e-/XPh w. same phosphor, front illum. CCD, corner..)

Size of detector area (1):

1. Background suppression:

- diffuse X-ray background is proportional with d^2

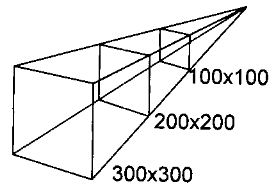




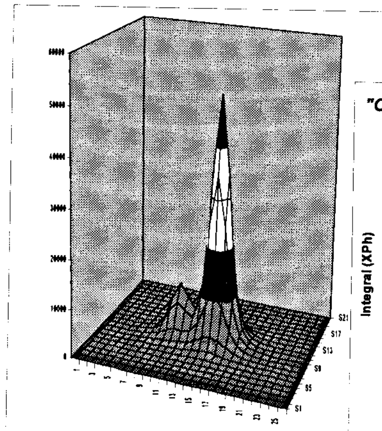
Size of detector area (2):

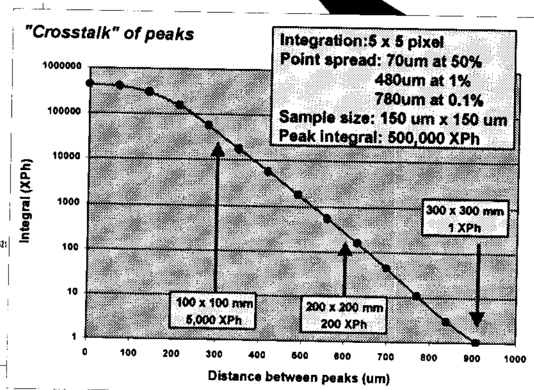
2. Resolution

Resolving power: closely placed diffraction peaks should be resolvable, even with large samples



Spot size is defin[illegible]marily by the sample size and phosphor r[illegible]ion...





Future trends in CCD detector technology

- Large area mosaic detectors based on fiber-optic taper demagnifiers (4x4)
- Lens coupled systems
- Fast readout imaging detectors

Development required:

- Phosphor / scintillator technology
- Multiple output, high resolution CCD's
- Lower priced, very large area CCD's

•Amorphous silicon based detectors ("Flat panel detectors")

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Conclusion:

- CCD technology is a well established technology for large area detectors
- Further improvements are possible
- Specialized CCD detectors (e.g. very fast readout cameras for time resolved applications) can be developed for future applications

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Thank you for your attention...

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